MEASUREMENT OF INSERTION LOSS FOR EMI SUPPRESSION FILTERS

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1 GENERAL

1.1 SCOPE

This document defines the method for measurement of the Insertion Loss of Radio Frequency Interference suppression filters. Mounting arrangements, test circuits and buffer-networks are described to accommodate the various constructions and circuit configurations of filters that may be encountered.

2 APPLICABLE DOCUMENTS

The following documents form part of this specification and shall be read in conjunction with it:

(a) ESCC Basic Specification No. 21300 - 'Terms, Definitions, Abbreviations, Symbols and Units.'

3 TERMS, DEFINITIONS, ABBREVIATIONS, SYMBOLS AND UNITS

The Terms, Definitions, Abbreviations, Symbols and Units as specified in ESCC Basic Specification No. 21300 shall apply. Other abbreviations are defined, as applicable, within the text of this document.

4 MOUNTING ARRANGEMENTS

4.1 GENERAL

The filter or component under test shall be mounted in an appropriate test container. Unless otherwise specified in the detail specification the test container shall be as follows.

4.1.1 Construction of the Container

The components which have no screens and coaxial plugs of their own at the input and output, are placed for measurements in a test container the dimensions of which depend on those of the article under test (e.g. on its length l, height h, and width w). A container is a box which is supplied with a lid and is made of non-magnetic metal. A container which is intended for measurement of feed-through capacitors and filters with flange mounting should have an internal partition with a hole for the mounting of capacitors and filters. Reliable electrical contact should exist between separate parts of the container. Separate parts of the housing are joined by soldering or continuous-seam welding; the lid and the housing are joined together by a spring-contact device or by a screw joint, and particular care shall be taken to ensure the lid makes good contact with the flange along its full length when measuring coaxial feedthrough capacitors and filters.

Coaxial jacks are mounted on two walls of the container.

4.1.2 Mounting of the Components in the Containers

The circuits in Figures II, III & IV refer to the most common arrangements. In the cases not included here, an arrangement shall be chosen approaching as nearly as possible the configuration in which the devices will be used.

4.1.2.1 Capacitors and Filters

(a) Non-feedthrough capacitors and multi-terminal filters

Capacitors with two-wire terminations shall be assembled as in Figure II(a), taking care that, unless otherwise specified, the length of each wire is 6mm and 50mm for bare wires and insulated wires respectively.
The capacitors with other than wire termination are mounted as in Figures II(b) and II(c).
The capacitors with one termination connected to the shielding case are mounted as in Figure II(c).
Delta capacitors are mounted as in Figure II(d) using three of the terminals (two), and tested without connecting the termination unused during the symmetrical test, but connecting such unused termination to the impedance Zo/2 (Zo being the impedance of the testing circuit) for the asymmetrical test. Four-terminal filters are mounted as in Figure II(d).

(b) Feedthrough capacitors and LC filters

Coaxial capacitors and LC filtering units with flange mounting are mounted as shown in Figure III(a).
LC filtering units and coaxial or non-coaxial feedthrough capacitors with a mounting other than a flange are mounted as shown in Figure III(b). Filters with screened leads are mounted as shown in Figure III(c).
If the mass connection is made through a wire termination, this wire shall be used in its original length and arranged in a straight line. Other kinds of terminals shall be connected to the metalwork by a wire as short as possible for use in practice.

4.1.2.2 Chokes

The mounting and connections of large-sized chokes are as shown in Figure IV(a) and small-sized chokes (with a diameter up to 10mm), supported by the terminations, are mounted as shown in Figure IV(b).

The provisions for the lengths and mountings of wire (or cable) terminations given in previous paragraphs are valid.

5 METHOD OF TEST

5.1 BASIC TEST CIRCUIT

The basic test circuit shall be arranged as shown in Figures V(a) and V(b). All elements of the circuit shall be screened. An asymmetrical (coaxial) test circuit shall be used for measurement of filters intended for asymmetrical interference voltage suppression and a symmetrical test circuit shall be used for measurement of filters intended for symmetrical interference voltage suppression in the frequency range up to 30MHz.

NOTE:
Practical modifications of test circuits shown are given in Para 7.

5.2 PRINCIPAL CHARACTERISTICS OF THE TEST CIRCUIT

The principal characteristics of the test circuit shall be within the limits given hereunder:

TABLE I - PRINCIPAL CHARACTERISTICS OF TEST CIRCUIT

CHARACTERISTIC OF TEST CIRCUIT	VALUE
Impedance	Any specific value between 50Ω and 75Ω
VSWR	Maximum 1.2
Symmetry coefficient (only for symmetrical test circuits)	Minimum 26dB
Accuracy: for insertion loss ≤ 80dB for insertion loss > 80dB frequency	 ±3dB ±6dB ±2%

NOTES
1. The characteristics given in the Table are maintained for each measurement frequency and for each current and voltage load value.

5.3 TEST EQUIPMENT

Substantial simplification of the measurement procedure can be achieved by using a suitable sweep generator and panoramic receiver tuned synchronously. The suppression characteristic may then be observed on an oscilloscope screen or automatically recorded.

5.3.1 Signal Generator

A sinusoidal signal generator is recommended. Generators of other signals (for example noise or impulse), which have a uniform output spectrum in the frequency range of interest, may be used, but in such cases the receiver shall have good selectivity and spurious rejection.

5.3.2 Receiver

A selective receiver (having at least one resonant circuit before the first amplifying stage) is recommended. The use of a non-selective receiver is acceptable if harmonic and other undesirable frequencies in the output of the generator are small enough not to affect the results of measurement.

5.3.3 Load Current or Voltage Source

The source providing loading current or voltage shall be floating and have both terminals (E and F in Figure V(b)) isolated from earth with the possibility of earthing any of them when it is appropriate.

Before testing the attenuation of the loaded filter, it shall be ascertained by a preliminary test made (Figure V(a)) without current or voltage (unloaded filter) that the tests in the frequency range considered are not influenced by the presence of the buffer-network UO and of the loading source impedance (Figure V(b)) by more than 1dB.

NOTES
1. Examples of realisation of buffer-networks are given in Para 8.

5.4 TEST PROCEDURE

Measurements shall be carried out in two steps. In the first step, the test circuit shall be arranged without the filter under test and the generator and the receiver shall be directly connected via suitable cable. The generator shall be adjusted to the desired frequency and the receiver tuned to resonance at the frequency of the generator. The output voltage of the generator and input voltage of the receiver shall be recorded. In the second step, the test circuit shall be arranged in filter-in condition and voltages shall once more be recorded.

An insertion loss of filter under test can be found from the formula:

$$A = 20\ log_{10}\frac{U_{01}}{U_{02}} + 20\ log_{10}\frac{E_{g2}}{E_{g1}} + A_{tt}$$

where:

U_{01} = input voltage of the receiver in filter-out condition
U_{02} = input voltage of the receiver in filter-in condition
E_{g1} = emf of the generator in filter-out condition
E_{g2} = emf of the generator in filter-in condition
A_{tt} = the value of attenuation (in decibels) for a calibrated attenuator which replaces the filter under test in an appropriate circuit (see para 7.)

NOTES

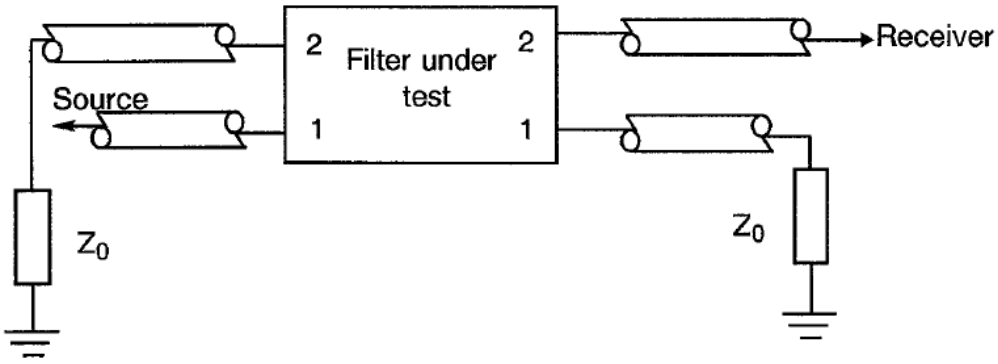
1. In practice, it is convenient to deal with readings from the generator (or receiver) only and for this purpose the second voltage is maintained at the constant level U_{01} (or $E_{g1} = E_{g2}$); for further details see Para 7.

5.5 CONNECTION OF FILTER OR COMPONENT UNDER TEST

Components and filters for two-wire circuits shall be tested respectively in symmetrical and asymmetrical test circuits.

Two-wire and multiple uncoupled circuit filters shall be tested for each lead separately. Z_0 shall be placed on all unused terminations and shall be consistent with the Z_0 of the line, generator and receiver. Additionally, coupling between individual leads shall be tested with the leads loaded with Z_0 as shown in Fig. 1 below:

FIGURE I - TEST FOR LEAD COUPLING



5.6 MOUNTING OF THE FILTER IN THE TEST CIRCUIT

Mounting of the filter in the test circuit shall correspond to that in normal use. The arrangement shall not disturb continuity and effectiveness of circuit screening. Unless otherwise specified, the filter under test shall be placed in a test container as specified in Para 4.1.

5.7 PRESENTATION OF RESULTS

The report of measurements shall contain the following specific data:

(a) Test circuit impedance.
(b) Results of measurements (for example, in the form of a table diagram showing the insertion loss in decibels as a function of frequency in orthogonal semi-logarithmic coordinates).
(c) Description (sketch) of connection and mounting of the filter in the test circuit, giving the shape and dimensions of the test container and connecting leads (if required).
(d) Maximum measurable insertion loss of test circuit (required only if it is within 10dB of the actually measured values of the filter under test).

6 METHODS OF VERIFICATION OF TEST CIRCUIT MAIN PARAMETERS

6.1 VOLTAGE STANDING-WAVE RATIO (VSWR) CHECKING

Method I:

The test circuit shall be divided at the points of connection of the filter under test into two parts, one which contains the generator and the other the receiver. Then the impedance of each of those parts shall be measured separately at the points of connection of the filter. VSWR shall be calculated (for each part separately) according to the following formula:

$$\mathrm{VSWR} = \frac{1+|\mathrm{r}|}{1-|\mathrm{r}|}$$

$$\text{where } \mathrm{r} = \frac{\mathrm{Z}-\mathrm{R}}{\mathrm{Z}+\mathrm{R}}$$

and

Z = complex value of measured impedance

R = rated resistance of the test circuit

Method II:
The test circuit shall be divided into two parts as in Method I. Then the VSWR shall be measured directly (for example, with the help of the slotted line) for each part separate. The maximum error of the VSWR measurement shall be ±5%.

NOTES
1. When checking the VSWR in the test circuit in which isolation attenuators are used, it is permissible to replace the generator and receiver by resistors of values equal to their rated resistances.
2. Circuit checks should also be made with buffer-network connected, when used.

6.2 ATTENUATION ACCURACY CHECKING
Accuracy checking shall be made with the help of a standard attenuator with the following characteristics:

(a) Attenuation of 50 ±0.5dB over the frequency range of interest.
(b) Maximum VSWR of 1.2 over the frequency range of interest.
(c) Input and output impedances matched to test circuit.
(d) Symmetry coefficient minimum 26dB (for symmetrical test circuits only).

The standard attenuator shall be inserted into the test circuit in place of the filter under test and its insertion loss shall be measured.

Test circuits containing buffer-networks and other arrangements for connecting a current or voltage source shall be checked with these included. The source itself shall be disconnected and terminals for its connection shall be short-circuited.

6.3 FREQUENCY ACCURACY
Checking shall be made with equipment having accuracies better than 2%.

6.4 MAXIMUM MEASURABLE INSERTION LOSS CHECKING
Maximum measurable insertion loss is limited by generator power, receiver sensitivity, leakage of signal from generator to receiver around the filters under test and by penetration of undesirable external signals. The test circuit shall be set up as shown in Figures V(a)(B) or V(b)(B) except that the filter under test shall be replaced by a short circuit, the insertion loss of which shall be measured. (An example of a realisation of this short circuit is shown in Figure V(c)).

If receiver voltage is more than 1 dB above the circuit noise level, then the maximum measurable insertion loss is limited by leakage of the test signal from the generator to the receiver or by undesirable external signals. Otherwise it is limited by the generator power or receiver sensitivity.

6.5 SYMMETRY COEFFICIENT CHECKING
The test circuit shall be divided at the point of connection of the filter under test into two parts, one of which contains the generator and the other the receiver. Then, using the auxiliary generator and auxiliary receiver, the voltages U_1 and U_2 shall be measured as shown in Figure V(d).

The symmetry coefficient shall be calculated from the formula:

$$k = 20 \log \frac{U_1}{U_2}$$

7 MODIFICATIONS OF THE BASIC TEST CIRCUIT

7.1 GENERAL

Measurements performed on the basic test circuit (Figures V(a)(B) and V(b)(B) require a previously determined reference level (0dB) in the circuits shown in Figures V(a)(A) and V(b)(A). If the stability of parameters of the equipment used is sufficient for maintaining the required measurement accuracy, then the test circuit may be calibrated once in the whole frequency range before the measurements. If stability is insufficient, then the test circuit must be calibrated separately before each measurement.

Examples of test circuits facilitating such measurements, which are equivalent to basic test circuits, are shown in Figures V(e), V(f) and V(g).

NOTES

If the filter under test is not mounted in an enclosed shielded container, these tests are performed on a conducting metallic plate, with all components connected to the plate.

The total length of each cable x and y in Figures V(e) and V(f) between the filter under test or the standard attenuator and the isolation attenuators, should be not more than 0.05 wavelength at any test frequency. Where difficulties in satisfying this condition arise, for example at frequencies above 50MHz, the test circuit shown in Figure V(g) may be used in place of that shown in Figure V(e). The two isolating attenuators in the branch containing the calibrated attenuator may be omitted if tests show that, with the coaxial switches in position 1, the VSWR requirement of Para 6.1 is maintained in the lines between generator and receiver. A corresponding circuit may be used in place of that of Figure V(f).

Measurements of loaded filters may also be performed according to the principles of Figures V(e), V(f) and V(g) but the filter under test shall be replaced by the set of elements shown in Figure V(h) (see Para 8).

7.2 GENERAL METHOD OF TEST WITH TWO COAXIAL SWITCHES (SEE FIGURE V(e))

Method I:

TR is omitted or A_{tt} is set equal to zero. The input voltage of the receiver shall be maintained at a constant level for filter-in and filter-out positions of the switches ($U_{01} = U_{02}$). Insertion loss shall be calculated from the formula given in Para 5.4 in which formula the first and last components are zero.

Method II:

TR is omitted or A_{tt} is set equal is zero. The emf of the generator shall be maintained, for both positions of the switches, at a constant level ($E_{g1} = E_{g2}$). Insertion loss shall be calculated from the formula in Para 5.4 in which the second and last components are zero.

Method III:
Both generator emf and receiver input voltage are maintained constant with the filter in, and with it replaced by a calibrated attenuator having 1dB steps. The first attenuation is then obtained from the formula in Para 5.4 in which the first and second terms are zero.

7.3 METHOD OF TEST WITH TWO COAXIAL SWITCHES AND CALIBRATED ATTENUATOR IN SERIES WITH THE FILTER UNDER TEST (FIGURE V(f))
The emf of the generator and the input voltage of the receiver shall be maintained at a constant level for both positions of the switches. The insertion loss (in decibels) of the filter under test shall be calculated using the formula:

$A = A_{T1} - A_{T2}$ (dB)

where:

A_{T1} = insertion loss of the calibrated attenuator with switches in Position 1.

A_{T2} = insertion loss of the calibrated attenuator with switches in Position 2.

FIGURE II - MOUNTING ARRANGEMENTS FOR NON-FEEDTHROUGH CAPACITORS AND FOUR-TERMINAL FILTERS

FIGURE II (a)

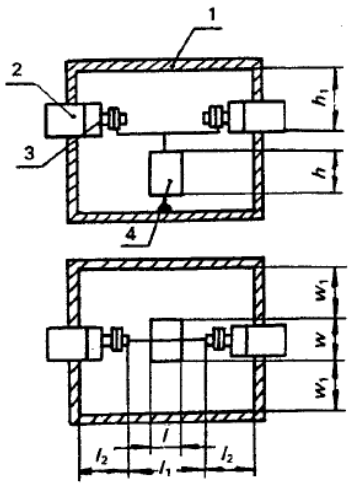


FIGURE II (b)

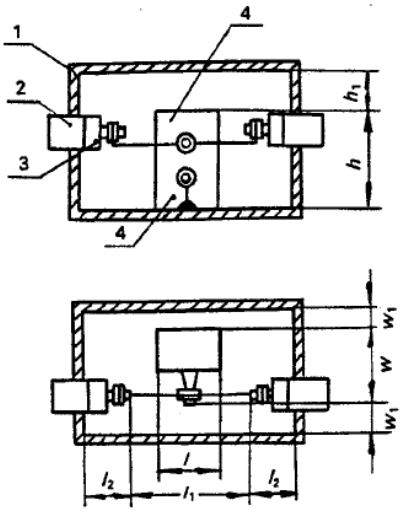


FIGURE II (c)

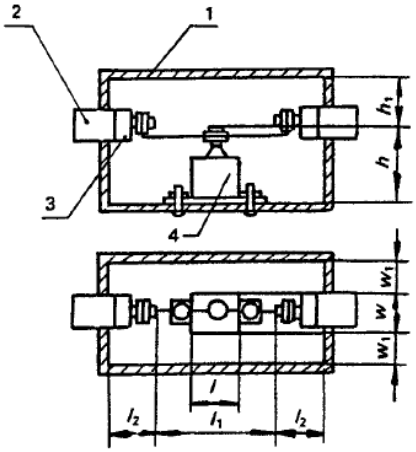
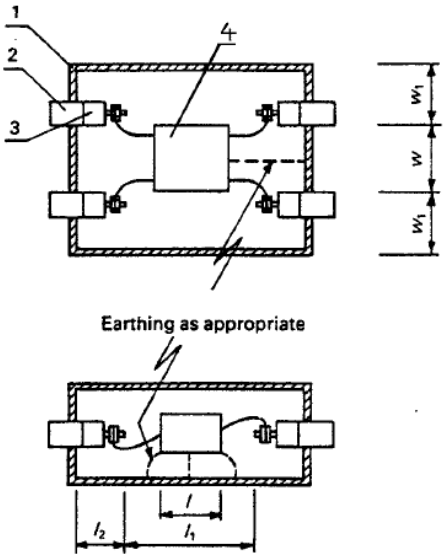


FIGURE II (d)



1 = container
2 = coaxial plug
3 = element of the mounting
4 = device under test

l_1 should not be greater than 1 + 20mm, l_2 not greater than 20mm. h_1 and w_1 should not be greater than 80mm.

NOTES

1. At high frequencies, the results of the measurements depend on the connections - these should be described in the test report.

FIGURE III - MOUNTING ARRANGEMENTS FOR FEEDTHROUGH CAPACITORS AND LC FILTERS

FIGURE III(a)

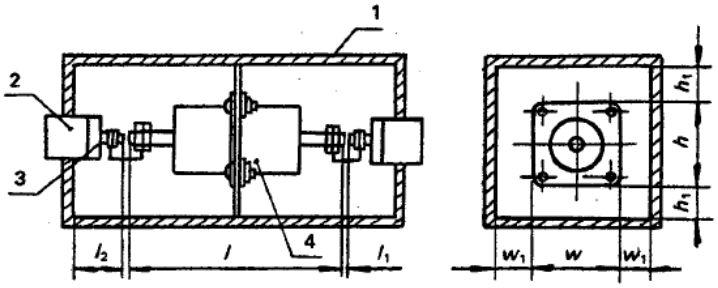


FIGURE III(b)

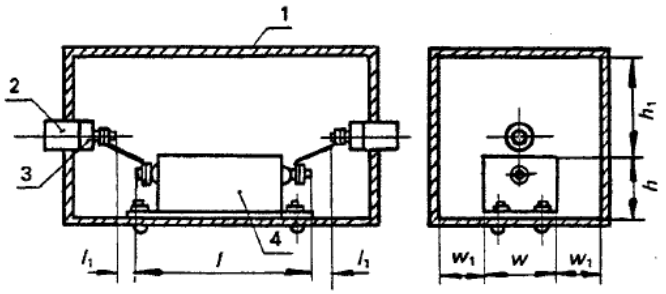
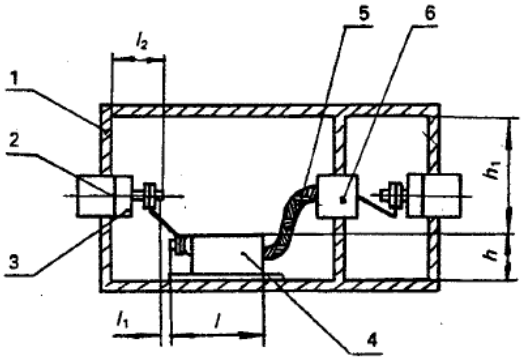


FIGURE III(c)



1 = container
2 = coaxial plug
3 = element of the mounting
4 = device under test
5 = screened lead
6 = screened plug

l_1 should not be greater than 10mm, l_2 not greater than 20mm. h_1 and w_1 should not be greater than 40mm.

FIGURE IV - MOUNTING ARRANGEMENTS FOR CHOKES

FIGURE IV(a)

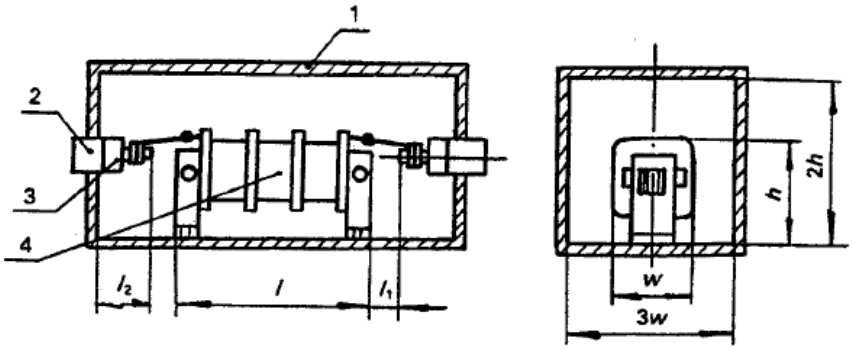
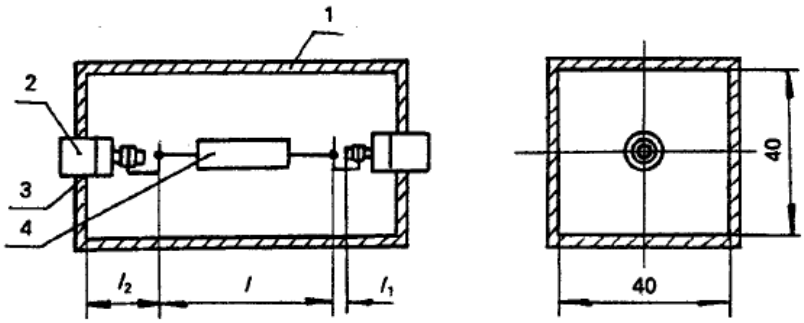


FIGURE IV(b)

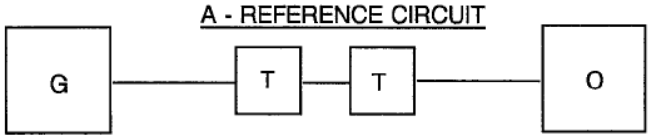


1 = container
2 = coaxial plug
3 = element of the mounting
4 = device under test

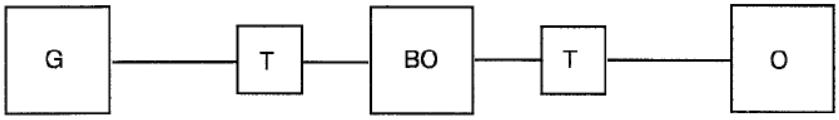
l_1 should not be greater than 10mm, l_2 not greater than 20mm. l = length of choke.

FIGURE V(a) - BASIC TEST CIRCUIT FOR MEASUREMENTS WITHOUT LOAD

A - REFERENCE CIRCUIT



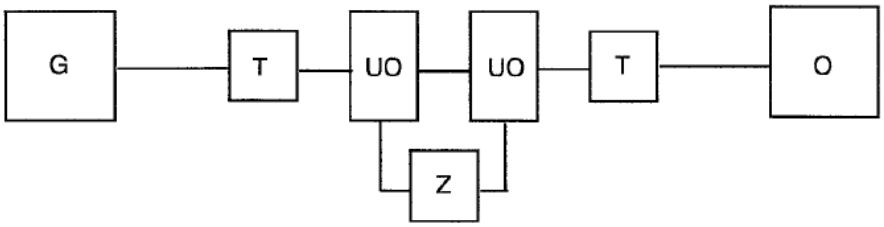
B - MEASUREMENT CIRCUIT



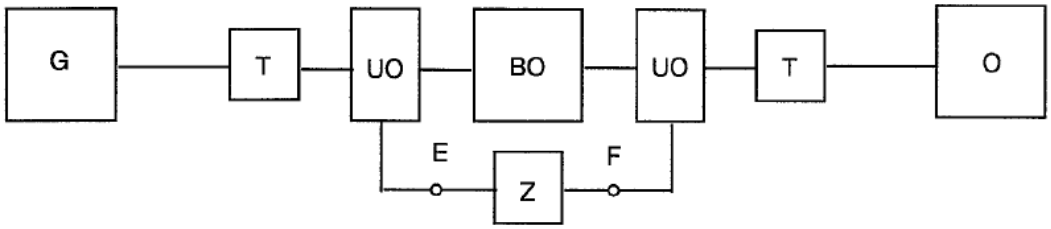
BO = filter under test
G = generator
T = isolating attenuator 10dB
O = receiver

FIGURE V(b) - BASIC TEST CIRCUIT FOR MEASUREMENTS WITH LOAD APPLIED

A - REFERENCE CIRCUIT



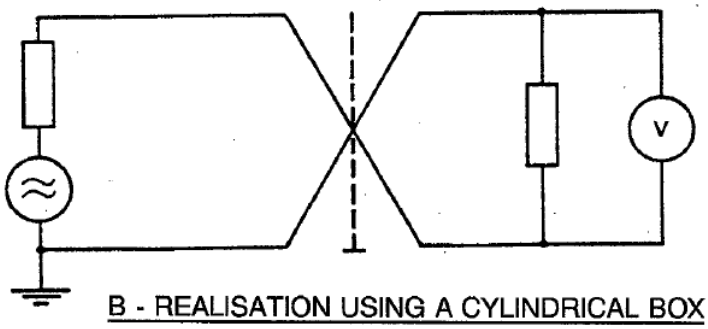
B - MEASUREMENT CIRCUIT



BO = filter under test
UO = buffer-network
O = receiver
T = isolating attenuator 10dB
G = generator
Z = current or voltage source, terminals E & F are not connected to earth.

FIGURE V(c) - EXAMPLE OF SHORT CIRCUIT IN TEST CIRCUIT

A - SCHEMATIC DIAGRAM



B - REALISATION USING A CYLINDRICAL BOX

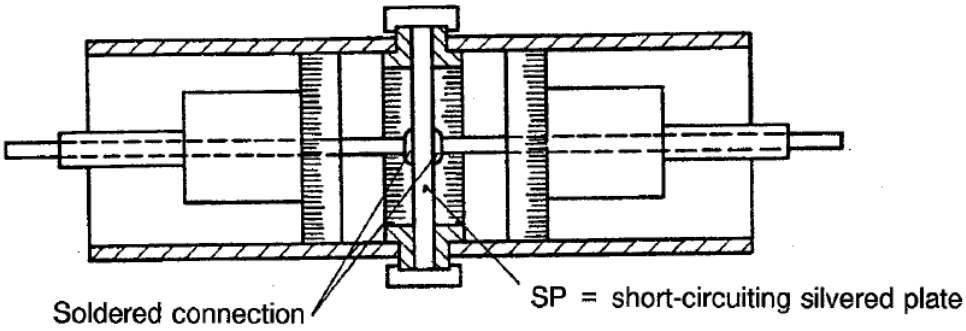
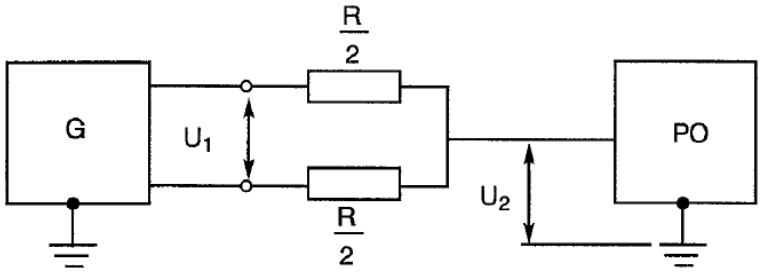
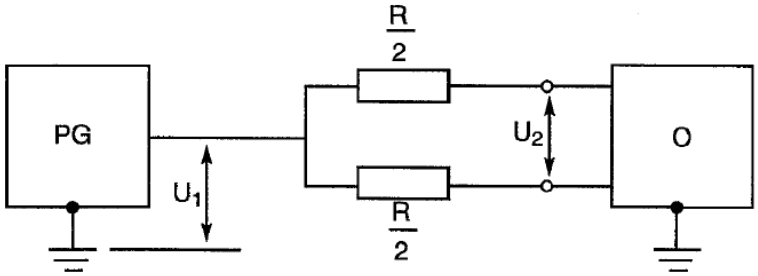


FIGURE V(d) - CHECKING OF SYMMETRY COEFFICIENT OF TEST CIRCUIT

A - CHECKING OF GENERATOR

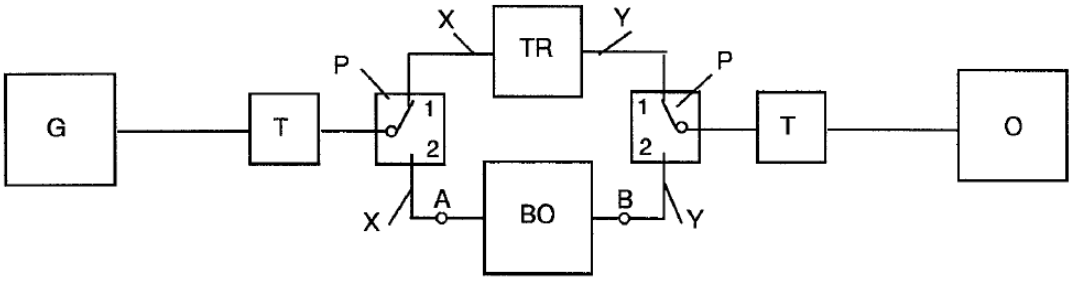


B - CHECKING OF RECEIVER



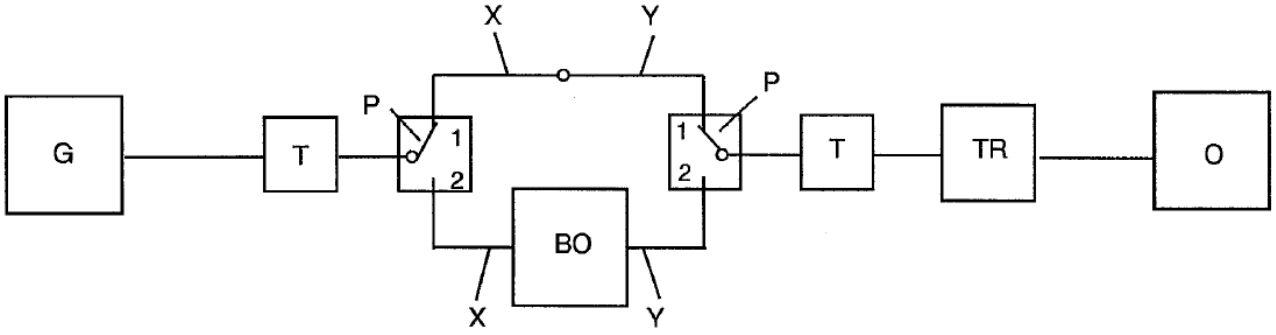
G = generator under test
R = resistor matched to generator or receiver under test
PO = auxiliary receiver with asymmetrical input
O = receiver
PG = auxiliary generator with asymmetrical output

FIGURE V(e) - TEST CIRCUIT WITH TWO COAXIAL SWITCHES AND CALIBRATED



G = generator
T = isolating attenuator 10dB
P = coaxial switch
O = receiver
BO = filter under test
X,Y = pairs of identical cables
TR = calibrated attenuator (adjustable)

FIGURE V(f) - TEST CIRCUIT WITH TWO COAXIAL SWITCHES AND CALIBRATED ATTENUATOR IN SERIES WITH THE FILTER UNDER TEST

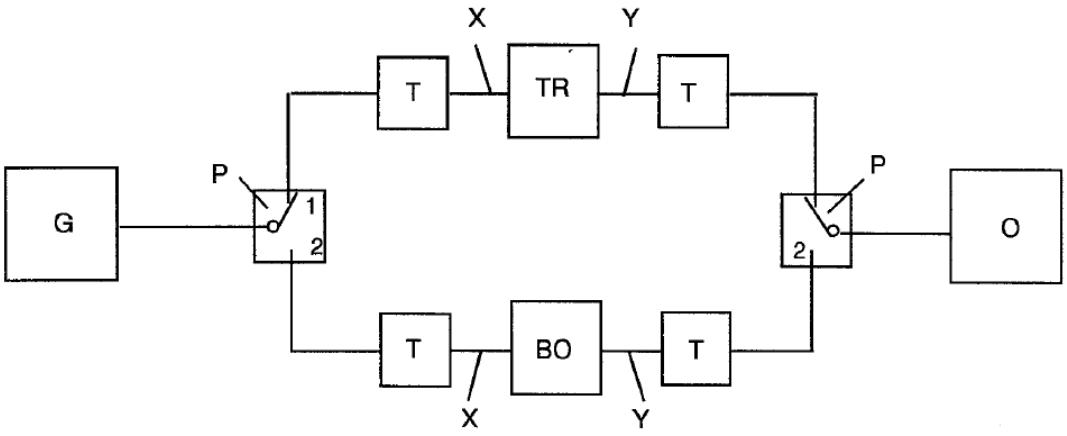


G = generator
T = isolating attenuator 10dB
P = coaxial switch
O = receiver
BO = filter under test
X,Y = pairs of identical cables
TR = calibrated attenuator (adjustable)

NOTES

1. In a variation of this circuit, the calibrated attenuator TR may also be placed immediately following the generator G or in fact may be incorporated within.

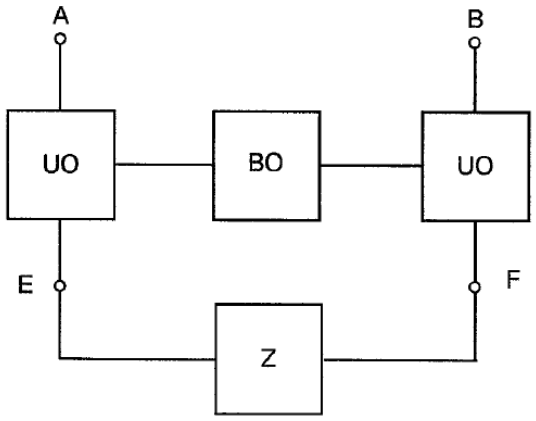
FIGURE V(g) - TEST CIRCUIT WITH TWO COAXIAL SWITCHES AND A CALIBRATED ATTENUATOR FOR PARALLEL SUBSTITUTION



G = generator
T = isolating attenuator 10dB
P = coaxial switch
O = receiver
BO = filter under test
X,Y = pairs of identical cables
TR = calibrated attenuator

N.B.: See note of Para 7.

FIGURE V(h) - SET OF ELEMENTS REPLACING FILTER UNDER TEST IN FIGURES V(E), V(F) & V(G)



BO = filter under test
UO = buffer-network
Z = current or voltage source

8 PRINCIPAL MEASURING CIRCUIT AND REALISATION OF THE BUFFER-NETWORK

8.1 PRINCIPAL MEASURING CIRCUITS

The ways of connecting buffer-networks for current and voltage load in test-circuits for asymmetrical, symmetrical and "V" tests are shown in Figures VI(b) to VI(g).

8.2 EXAMPLES OF BUFFER-NETWORKS

8.2.1 Buffer-Networks Covering Frequency Ranges

Typical circuit diagrams of buffer-networks for tests with load for the frequency ranges of 0.1MHz to 30MHz, and greater than 30MHz, are shown in Figure VI(a). Specifications of the elements of these buffer-networks are given in the Table II.

Before testing the attenuation of the loaded filter, it shall be ascertained by a preliminary test made without current or voltage (unloaded filter) that the tests in the frequency range considered are not influenced by the presence of the buffer-networks UO and of the source Z.

TABLE II - ELEMENTS OF THE BUFFER NETWORKS

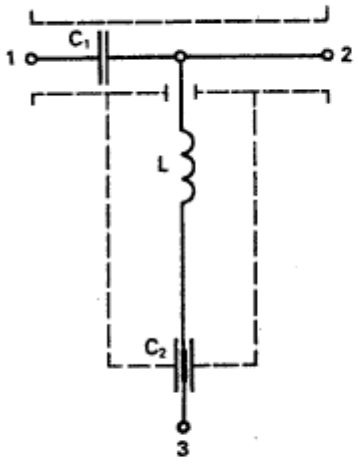
ELEMENT	0.1MHz TO 30MHz	GREATER THAN 30MHz
C1	Non-inductive capacitor 0.1µF	Non-inductive capacitor 2nF
C2	Feedthrough capacitor 1µF/100A	Two feedthrough capacitors 1µF/100A
L	Split winding choke Seven sections: each section 20 turns in five layers. Width of section about 20mm Distance between sections about 6mm Cotton-covered 4mm Ø wire Open ferrite core: seven 8mm Ø x 200mm rods of Ni-Zn ferrite with μ_i = 200 Choke length: 176mm Choke diameter: 75mm $L_{1\ kHz}$ = 1.2mH	Each choke: One layer winding, 12 turns Cotton-covered 3mm Ø wire Open ferrite core: 8mm Ø x 42mm rod of Ni-Zn ferrite with μ_i = 200 Choke length: 45mm Choke diameter: 14mm $L_{1\ kHz}$ = 2µH

NOTES

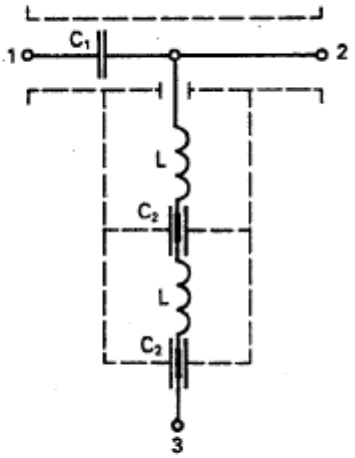
1. Buffer-networks for which parameters are given in the Table are designed for 60A continuous load and 100A short-time load. Forced cooling may be necessary.

FIGURE VI(a) - EXAMPLE OF BUFFER-NETWORKS FOR TEST WITH LOAD

A - FOR THE FREQUENCY RANGE OF 0.1MHz to 30MHz

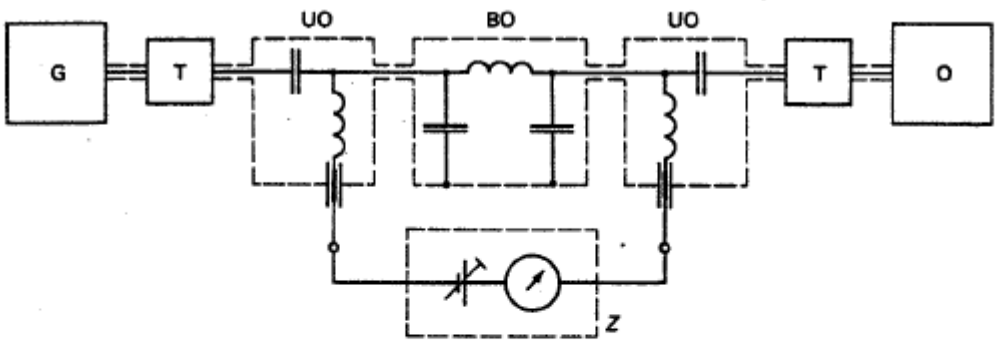


B - FOR THE FREQUENCY RANGE OF >30MHz



1 = to the generator or receiver
2 = to the filter under test
3 = to load current or voltage source

FIGURE VI(b) - EXAMPLE OF CONNECTING BUFFER-NETWORKS FOR LOAD CURRENT SOURCE IN ASYMMETRICAL TEST CIRCUIT

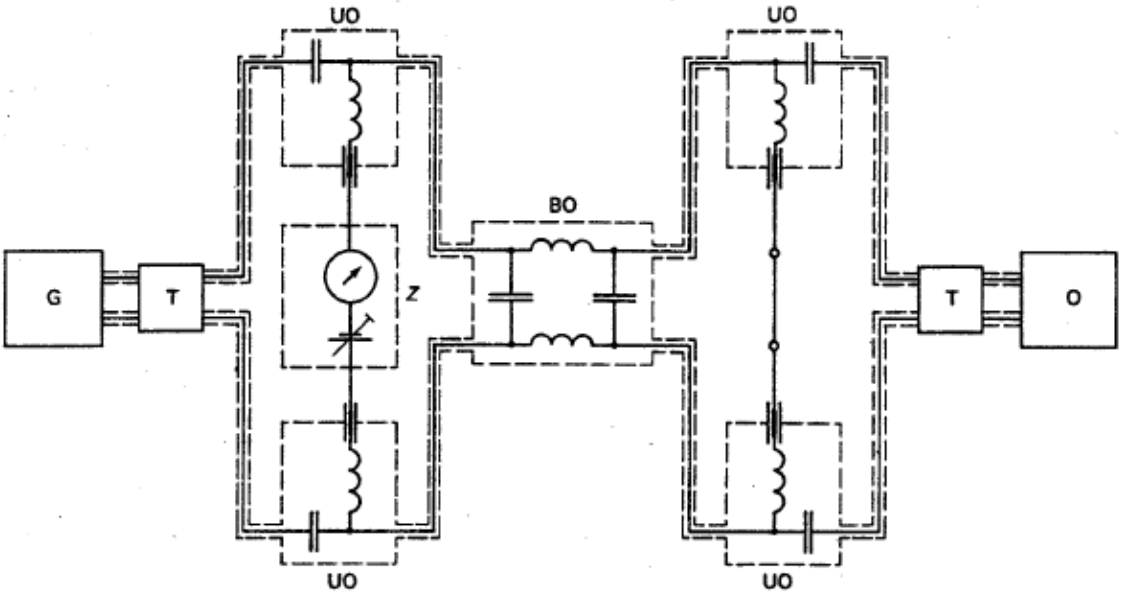


BO = filter under test
G = generator
O = receiver
T = isolating attenuator 10dB
UO = buffer-networks
Z = load current source

NOTES

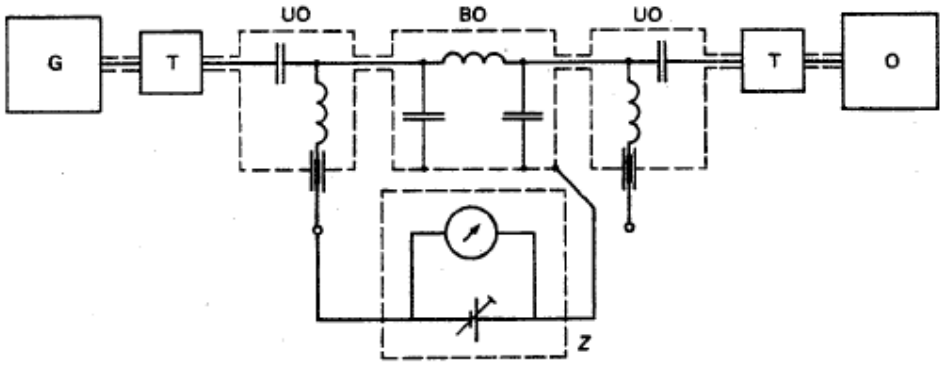
1. Not valid for filters with multiple circuits using winding on one or more common magnetic stores.

FIGURE VI(c) - EXAMPLE OF CONNECTING BUFFER-NETWORKS FOR LOAD CURRENT SOURCE IN SYMMETRICAL TEST CIRCUIT



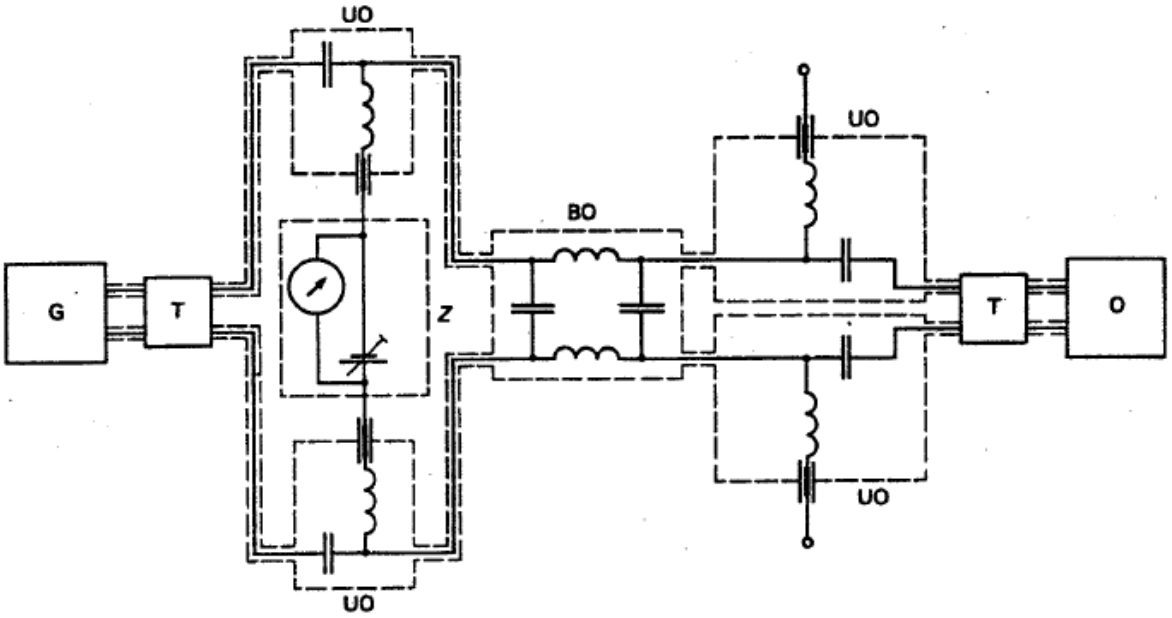
BO = filter under test
G = generator
O = receiver
T = isolating attenuator 10dB
UO = buffer-networks
Z = load current source (see note, Figure VI(e))

FIGURE VI(d) - EXAMPLE OF CONNECTING BUFFER-NETWORKS FOR LOAD SOURCE IN ASYMMETRICAL TEST CIRCUIT



BO = filter under test
G = generator
O = receiver
T = isolating attenuator 10dB
UO = buffer-networks
Z = load current source

FIGURE VI(e) - EXAMPLE OF CONNECTING BUFFER-NETWORKS FOR LOAD SOURCE IN SYMMETRICAL TEST CIRCUIT

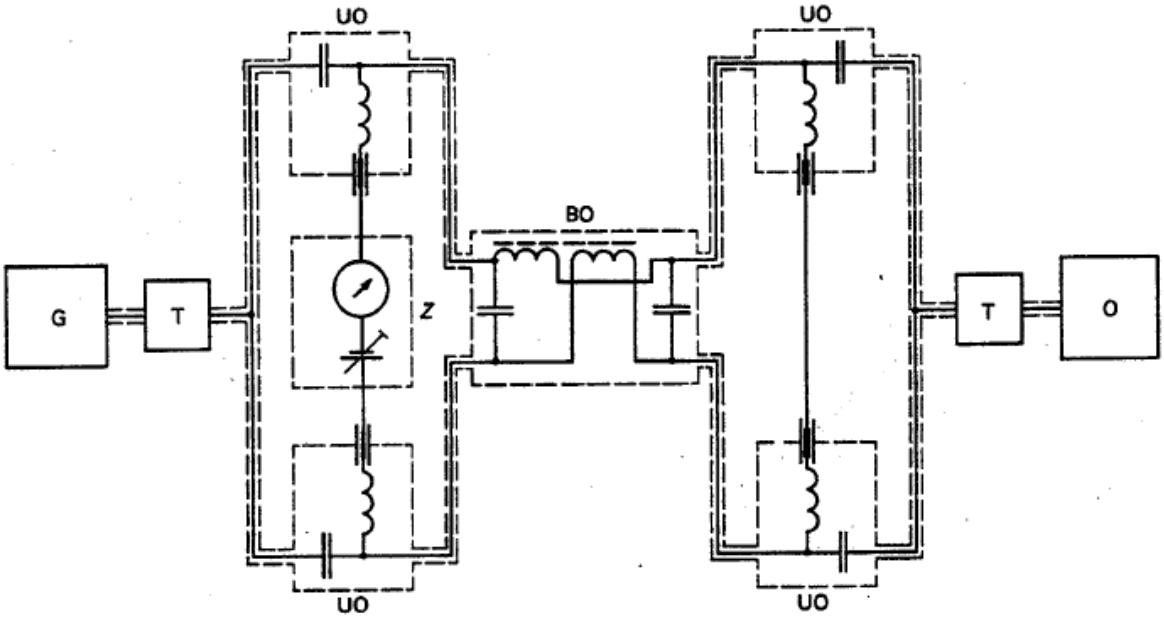


BO = filter under test
G = generator
O = receiver
T = isolating attenuator 10dB
UO = buffer-networks
Z = load current source

NOTES

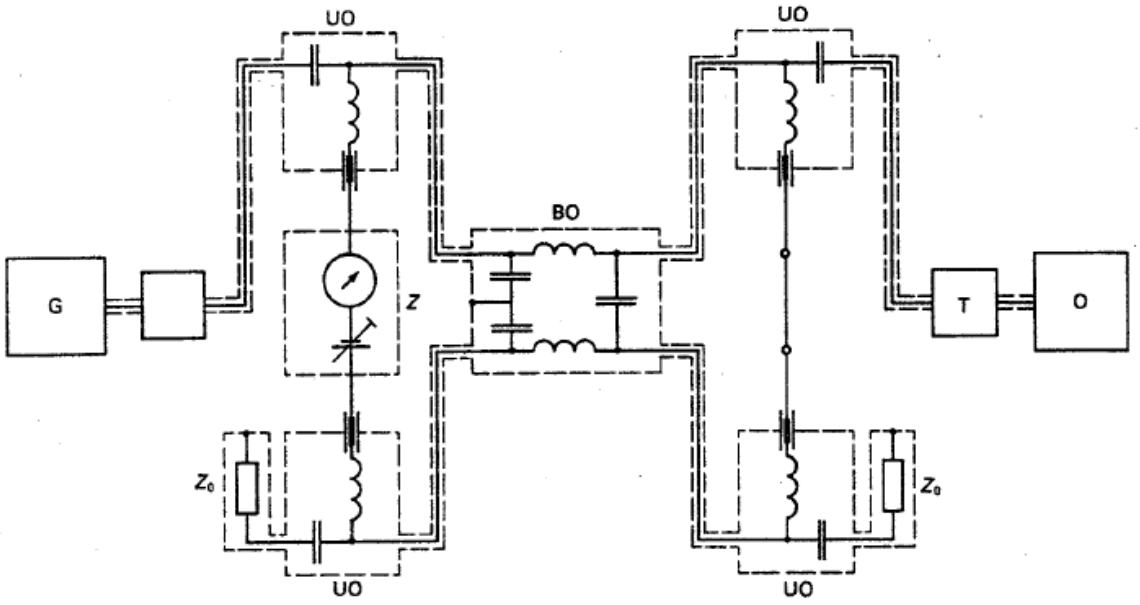
1. In the symmetrical test circuits shown in Figures VI(c) and VI(e), the symmetrical generators and receivers may be replaced by asymmetrical generators and receivers used in conjunction with appropriate unbalance to balance transformers.

FIGURE VI(f) - EXAMPLE OF CONNECTING SYMMETRICAL FILTER FOR ASYMMETRICAL INSERTION LOSS MEASUREMENT



BO = filter under test
G = generator
O = receiver
T = isolating attenuator 10dB
UO = buffer-networks
Z = load current source

FIGURE VI(g) - EXAMPLE OF CONNECTING BUFFER-NETWORKS FOR LOAD CURRENT SOURCE IN 'V' TEST CIRCUIT FOR TWO-LINE FILTERS



BO = filter under test
G = generator
O = receiver
T = isolating attenuator 10dB
UO = buffer-networks
Z = load current source
Z_o = impedance of test circuit